



MOKELUMNE WATERSHED AVOIDED COST ANALYSIS:

Why Sierra Fuel Treatments Make Economic Sense



Appendix E: FERGI - Estimated Postfire Gully Erosion in the Mokelumne Watershed

E.1 Abstract

The Fire-Enhanced Runoff and Gully Initiation Model (FERGI) was used to estimate the amount of sediment that might be produced from gully erosion in the Mokelumne watershed following large wildfires under both the no-treatment and post-treatment scenarios. FERGI estimates the probability of runoff generation and gully initiation on hillslopes after fires. The model uses stochastically generated weather time series as inputs to determine the probability of particular outcomes. Results include return intervals for runoff generation rates and totals, upslope extent of gully initiation (channel extension), and the changes that might be expected with fuels treatments.

E.2 Model Purpose

After fires, water repellency can decrease the infiltration capacity of soils (for example, DeBano, 1981) and the loss of surface organics can increase the mobility of soil particles. Together these effects increase the likelihood of runoff and erosion compared to unburned conditions, particularly during intense thunderstorms. In response to the increased risk of runoff and erosion, land managers and technical specialists sometimes apply erosion control efforts to reduce the consequences. Because of the brief window of time that risks are increased, and because of the strong dependence of fire related erosion on severe weather events, empirically demonstrating the effectiveness of these treatments has thus far proven to be an elusive task.

In part, the problem is that the effectiveness is not a constant percentage reduction or some similar parameter, but depends on the amount and intensity of rain received. For very tiny storms, treatments do nothing. Conversely, they can be overwhelmed by large storms. For a range of storms between these extremes, we would expect a varying degree of effectiveness. Quantifying an estimate of this effectiveness function is most efficiently done using simulations. Such simulations require an accurate, physically based mathematical description of the hillslope hydrologic and geomorphic response to a given set of weather events and a means for describing the potential series of weather events (e.g. a stochastic weather model). The resulting output provides an estimate of the effectiveness as a function of storm return periods.

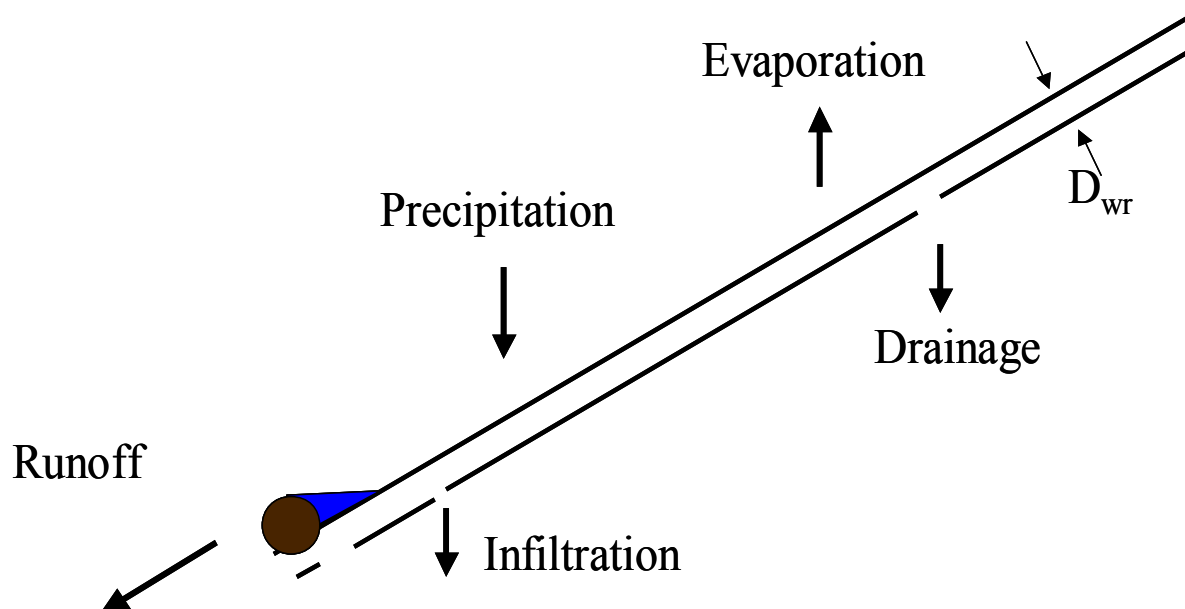
E.3 Model Design

FERGI comprises a stochastic climate generator and a deterministic hillslope hydrology and geomorphology model. The stochastic climate generator model is a k-nearest neighbor resampling model based on Rajagopalan and Lall (1999). It simulates daily sequences of precipitation and temperature using information from the preceding day's precipitation and temperature and a set of similar days drawn from the historical record. Once the daily precipitation total is estimated, a second resampling draws from the 15-minute precipitation data set for days with similar

precipitation totals within an 18-day window, and wind speeds are similarly selected from a separate wind speed data set. The stochastic data are fed to a hydrology model.

The water repellent layer that may form after fire is generally underneath a shallow wettable layer (< 10 cm thick) of soil (DeBano, 1981). The water repellent layer is discontinuous, allowing water to penetrate through regions with lower repellency. FERGI calculates the water balance of the thin wettable layer of soil overlying the water repellent layer of depth D_{wr} (Figure E.1). The model shares its physical basis with the conceptual approach proposed by Shakesby and others (2000), and goes a step further in numerically estimating the components of the water balance given driving weather. The water balance of the thin layer is maintained with both short term and long term components (Figure E.1). The long term components include drainage and evaporation that reduce the water content of the layer over days. Potential evaporation is based on daily climate simulation and modified by the water content of the surface layer. Drainage brings the surface water content to field capacity by the end of each day. The short term components are precipitation and infiltration that occur during brief precipitation events. Precipitation is provided by the stochastic climate generator as a series of intensities and durations. Infiltration capacity is estimated as the mineral soil saturated hydraulic conductivity multiplied by the fractional water repellent area. Contour felled logs add a component of surface storage and decrease the fractional water repellent area. Runoff is precipitation that is excess to infiltration and storage within the shallow layer. Runoff is routed using a kinematic wave approach to estimate the depth of flow as a function of contributing hillslope distance and, consequently, shear stress. The shear stress is compared to critical shear stress for initiation of particle motion to estimate where gullies might initiate during an event (Istanbulluoglu and others, 2002).

Figure E.1: Schematic of the hillslope hydrology in FERGI.



E.4 Running the Model

The user is asked to specify the weather stations used for the stochastic climate simulation and to supply some simple soil and hillslope information for the model runs. Climate station selection is accomplished in an ArcIMS environment so that users can select stations that are near the site geographically and most similar to the site climatically in their judgment. Soil characteristics that need to be estimated are median grain size and mineral soil hydraulic conductivity, for which there are published relationships to soil texture. In addition, they will be asked to supply the fractional water repellency for the area and the average depth to the water repellent layer, which can be measured or estimated. Fractional water repellency and depth to the water repellent layer were estimated based on previous work in diverse settings that all had roughly the same results. Despite substantial differences in bedrock and soil structure, sites in Idaho and Montana showed very similar patterns in fractional water repellent area immediately after fire and declining with time. Under severe conditions fractional water repellency ranged from 90 to 99% on 100-m transects. Averaging across many transects for particular study units, numbers were close to 95% in several locations as first-year water repellency. These results were partially published and discussed in Luce et al. (2012). The model results were relatively insensitive to depth to water repellent layer within a reasonable range.

The slope and average hillslope length before channel inception complete the list of information needed about site characteristics. Information needed about treatments consists of the amount of surface water detention provided by treatments and the areal fraction of the hillslope that is trenched, perforating water repellent layers. Guidance is provided for all inputs.

Output from the model is provided as graphs and tables that can be put into graph making programs such as Excel. The amount of runoff and location of potential gully initiation points will be key metrics.

E.4.1 Description of gullies resulting from post-fire storm in December 2005

Field measurements of two gullies that formed during a major storm shortly after the Power Fire, a 17,000 acre fire that burned within the Mokelumne watershed in 2004, were made by Alan Janicki of the Stanislaus National Forest, and provide a basis for estimating the dimensions of gullies that might be initiated following a major wildfire as modeled using FERGI. Both gullies were observed within a salvage sale unit. As reported by Janicki (written commun., 2006):

“The lower half of the unit has a gully that has downcut into deep non-cohesive loamy material, possibly an old landslide deposit. The subsoil appears to be particularly erodible. The gully has two segments referred to as the upper gully and the lower gully. The upper gully is 125 ft long and averages 6 ft deep by 13 ft wide. The lower gully is 175 feet long and averages 5 ft deep by 10 ft wide. Both gullies have incised channels on relatively steep slopes. The slopes are 18% and 27% where the lower gully has cut its channel. The upper gully is located on a 21% slope. Approximately 700 plus cubic yards of soil has been removed by the two gullies. Both gullies are unstable and have potential for further headcutting during large storm events.”

The storm that apparently initiated these gullies in late December 2005 was approximately a 10-year 24-hour storm. The design storm used in the FERGI model was a 2.5 year storm. Therefore,

the gully dimensions measured in the field likely overestimate the dimensions of gullies generated by a storm of the intensity and duration used in the FERGI model. However, these were the only measurements available for post-fire gullies in the Mokelumne watershed, and their dimensions were used in conjunction with FERGI results as described below to estimate post-fire gully sediment production for the no-treatment and post-treatment scenarios.

E.4.2 Post-fire No-Treatment Scenario

FERGI results for the post-fire no-treatment scenario indicate a total of 181,232 30-meter pixels with gully erosion or channel extension. These results were converted to aggregate erosion volume and mass using the average dimensions of gullies measured after the Power Fire, which had average width of 11.5 feet and average depth of 5.5 feet. Based on photographs of the gullies observed in the field, the actual channel cross sections more closely resembled rectangles. Average cross-section gully area was therefore 63 square feet, or 5.9 square meters, assuming a rectangular channel shape.

For a rectangular channel, total erosion volume per 30-meter pixel is computed as average cross-sectional area multiplied by the 30-meter width of the pixel, or 176 m³. Assuming a reasonable bulk density of 1.5 Mg/m³, total erosion mass per pixel is 265 Mg, or metric tons. Multiplying by the total number of eroded pixels (181,232) gives a total of 47,946,868 Mg. Using a drainage basin area of 1,500 km², the gully-related sediment yield is 31,965 Mg/km² or 320 Mg/ha.

E.4.3 Postfire Treatment Scenario

FERGI results for the postfire treatment scenario indicate a total of 85,282 30-meter pixels with gully erosion or channel extension. These results were converted to aggregate erosion volume and mass as described above using the average dimensions of gullies measured after the Power Fire.

For a rectangular channel, total erosion volume per 30-meter pixel is estimated, as described above, at 176 m³. Assuming a reasonable bulk density of 1.5 Mg/m³, total erosion mass per pixel is 265 Mg, or metric tons. Multiplying by the total number of eroded pixels (85,282) gives a total of 22,562,267 Mg. Using a drainage basin area of 1,500 km², the gully-related sediment yield is 15,042 Mg/km² or 150 Mg/ha.

E.5 Comparison of Scenarios

The estimated post-treatment sediment yields for gully erosion, for either channel shape, are roughly 47% of the yields for the no-treatment scenario. The model therefore predicts that treatments to reduce fire severity would reduce post-fire gully erosion by 53% for the design storm. As noted above, these estimates are based on gully dimensions resulting from a higher magnitude storm, and may therefore be higher than sediment yields for a 2.5 year storm.

References

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Disclaimer

This report is rich in data and analyses and may help support planning processes in the watershed. The data and analyses were primarily funded with public resources and are therefore available for others to use with appropriate referencing of the sources. This analysis is not intended to be a planning document.

The report includes a section on cultural heritage to acknowledge the inherent value of these resources, while also recognizing the difficulty of placing a monetary value on them. This work honors the value of Native American cultural or sacred sites, or disassociated collected or archived artifacts. This work does not intend to cause direct or indirect disturbance to any cultural resources.

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